3D models for teaching and learning geoscience

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Abstract

Although 3D geological models have been used in teaching as early as 1841, recent developments in 3D geological modelling methods and visualisation at the British Geological Survey (BGS) are providing unique resources for teaching and learning geoscience in the 21st century.

Today's geoscience students utilise a variety of cognitive processes and spatial skills during their learning experience. These include the application of schema's, image construction, detecting patterns, memorising figures, mental manipulation and interpretation, making predictions and deducing the orientation of themselves and the rocks around them.

Digital 3D geological models allow students to visualise and interrogate geology; they reinforce spatial skills, facilitate student recognition of pre-learnt geological principles in the field and encourage students to think about geological processes and properties. In turn they assist students when they convert 2D field, map and GIS outputs into three dimensional geological units, a widespread difficulty for many students of geology.

Figure 1: The 3D Models for Teaching Team discussing learning points that can be explored through 3D geological models.

Introduction

The British Geological Survey has been producing and developing digital 3D geological models using GSI3D (Geological Surveying and Investigation in 3 Dimensions) software for over 10 years (Figure 1). Originally developed by Hans-Georg Sobisch in Lower Saxony, Germany, the models produced from GSI3D are revolutionising the working practices, data standards and products of the Survey as a whole and it is felt they have great potential as a teaching resource for undergraduates and beyond. Sharing our geoscience information with academia is highlighted throughout the BGS strategy as is instilling practical skills in future geoscience professionals, such as model building and interpretation. In 2009 a year-long scoping study was launched to investigate the potential of the models as a teaching resource for foundation geoscience. The study included justifying if and how the models help students to learn geoscience; how models have been used historically and how other forms of modelling are being used today. A questionnaire was sent to universities in the UK and demonstrations provided to discuss the advantages and disadvantages of using models for teaching. The project's objectives were:

- How can 3D geological models help students learn geology?
- What geological concepts can the models show?
- How have 3D models been used in the past for teaching?
- What do UK universities want from these models?
- Develop a 3D model, student/tutor user-manual and learning exercises (Figure 2).

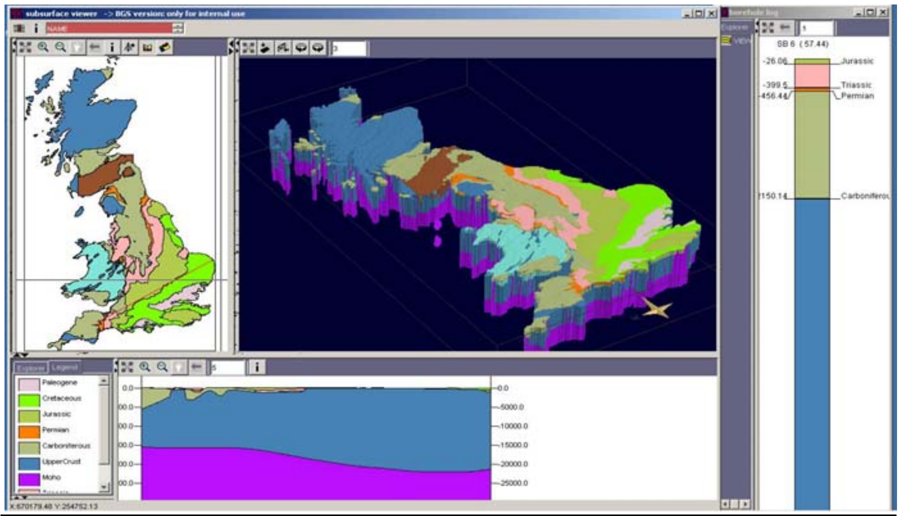

Figure 2: 3D geological model of the UK

What mental processes are involved in learning geoscience?

Spatial thinking, from a molecular to an outcrop to a planetary scale, is a crucial skill when learning in the geosciences. This encompasses observation skills such as recognition, description, classification, location and orientation. This is followed by mental manipulation and interpretation of what has been observed in order to deduce the properties, processes and prospects of an area (Kastens and Ishikawa, 2006). Geospatial skills therefore, also require memory and communication.

During a geoscience student's education they will need to locate themselves or a location on a map at some stage and this involves being able to translate what is found in the complex three-dimensional, real world to a flat, two-dimensional piece of paper (Kastens, 2006). Often the student will need to mentally picture a landscape feature from different perspectives; Shepard and Metzler (1971 in Kastens and Ishikawa, 2006) found that people take longer to identify features as the angle disparity increases from 0 to 180 degrees, this indicates that people mentally rotate drawings as if they were physical objects in space; the study also highlighted that although there is a wide difference in performance on this test, males generally outperform females. For geologists, recognising patterns in the field is further complicated by the fact that patterns and structures can be much changed in reality due to erosion or deformation. A geologist has no assurances that a particular geological structure will be there and the background, within which the pattern may be, is more complex.

Dip is the maximum angle of the slope of an inclined rock surface; it has another component, the direction the bed is dipping in – north, south, east or west – this is always 90 degrees (perpendicular) to the strike. The **Strike** is the direction of a horizontal line on an inclined surface and is measured from true north. Geoscience students find dip and strike a tough concept to learn and this could be linked to people generally finding absolute (such as downhill and uphill) frames of reference more difficult to use than relative ones (such as front, back, left and right). Findings have suggested that a technical geological map that communicates well with other geoscientists may not communicate well with students of low-spatial ability.

How can 3D models enhance the learning of geoscience?

Pedagogical modelling (conceptual or physical) in the geosciences can involve the building of a model to represent the knowledge and characteristics of an area. This may include visualisation, evaluation, measurement and uncertainty assessment. The model can then be used as an aid to find a solution to a problem. Like most scientific models that are a product of countless scientific inquiries they therefore illustrate the nature of science within a wider context. The model described above, whether a mental or a digital 3D version is an example of acting in an authentic scientific approach that can instil scientific reasoning and understanding in students; therefore better preparing them for a life as a professional geoscientist.

Although authentic inquiry can be difficult to define it can certainly be implemented through digital 3D geological models where the student can focus on contemporary scientific problems. If these are of personal significance it will enhance understanding by keeping the students attention and motivation for longer.

Herbert (2006) states that information technology should be at the forefront of complex earth system education and incorporate authentic inquiry and Rapp & Uttal (2006) believe these types of visualizations will be increasingly used in teaching situations for the foreseeable future. The strengths for this output lie in the availability of large datasets, innovative learning materials and the Internet that can be easily utilised by students and tutors alike and the fact that so many of today’s students are highly specialised at using information and communication technologies. The rate of development of this sector in the last 10-15 years alone has been phenomenal and is therefore likely to continue at a similar rate. We have a responsibility to equip geoscience students with cutting edge technology skills, such as those needed in 3D geological modelling and GIS, so they are able to deal with environmental issues in their professional lives.

Transforming 1 or 2D observations into 3D mental pictures or 4 dimensional (time) objects or structures is a problem shared by many Earth and environmental science disciplines. The human eye and brain are very good at identifying patterns within visual disorder (Gilhooly, 1988 in Kastens and Ishikawa, 2006). Therefore presenting geological information visually, such as topography in a 3D model, taps into this natural ability and makes it much easier for geoscientists to recognise geological configurations. With practice this becomes easier and is supported by Carroll's (1993 in Kastens and Ishikawa, 2006) embedded figures test where an individual has to perceive and hold an image in their memory and then go on to detect it within complex and distracting patterns. Hock *et al* (1974 in Kastens and Ishikawa, 2006) found that this task is harder if the orientation of the desired figure is altered and Hanawalt (1942 in Kastens and Ishikawa, 2006) concluded that people improve after practice.

Siegel and White (1975 in Kastens and Ishikawa, 2006) provided examples of where the spatialization of non-spatial information seems to facilitate memory, retrieval of remembered information, and the solution of reasoned problems. Within an educational 3D geological model students should demonstrate evidence of being able to reason scientifically and engage in scientific inquiry. When learning is focused on challenging scientific problems with personal significance, the student's efforts are reinforced, and evidence-based reasoning is developed from personal observation and experiences. 3D visualizations are especially useful when a topic is challenging to present because of pragmatic, financial, or motivational issues therefore these types of representations of geology will continue to enjoy an increased usage in the classroom.

Reynolds *et al* (2006) present 3D visualisation modules in phases; first an exploration phase, then a phase of introducing geological terms and concepts and finally applying this knowledge to a problem. Crucially these 3D representations allowed activities that would not have been possible on paper-based curricula such as rotating and slicing into a block of geology. The students were encouraged to participate actively by getting them to describe, draw and make predictions about the geology and then apply this experience to novel situations or problems. On line quizzes were integrated throughout. Importantly, student performance was measured through a geospatial test before and after the modules had been worked through. General spatial skills were found to have improved by comparing normalised gain scores (normalised gain is worked out by dividing the amount of improvement by the total room for improvement), mean gain scores were 60% for the experimental students and 45% for the control group. Interestingly, the difference between the genders was also eliminated.

Methodology of digital 3D geological models at BGS.

Model building at BGS using GSI3D software requires a digital elevation model, surface geological line work and borehole data to enable the geologist to construct cross sections by correlating boreholes and the outcrops to produce a geological fence diagram. Geologists' draw their sections based on physical evidence such as borehole logs and by their understanding of earth processes, examination of exposures and theoretical knowledge (Figure 3).

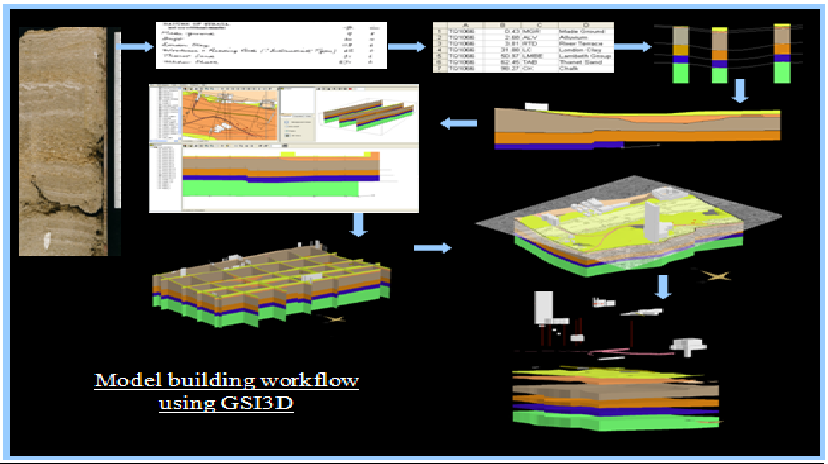

Figure 3; Model building workflow using GSI3D.

BGS Geological Models are embedded within a subsurface viewer and can be examined and analysed to produce:

- Models displaying the geology or other pre-selected applied themes (e.g. Hydrogeological properties)
- Geological maps (at surface and uncovered)
- User defined synthetic borehole logs
- User defined horizontal slices and vertical sections
- Visualisation of the geometry of single and combined units

Potential new educational capabilities of the models involve adapting the viewer with student specific tools such as:

- A cross section tool that allows the student to draw their interpretation on screen before presenting the model's -version for comparison
- True/apparent dip tool allowing the student to estimate dips and then get the software to display the quality of their guess against the real value

The models are currently provided with a concise user manual for the Subsurface Viewer. Many students have given positive feedback about the user manual and have been able to easily manipulate and analyse 3D geological models within the Lithoframe Viewer.

Questionnaire to UK Universities

A questionnaire was sent to university geology/geography departments in the UK. Eleven were completed and analysed. Some of the results are shown in Figures 4-6

Results

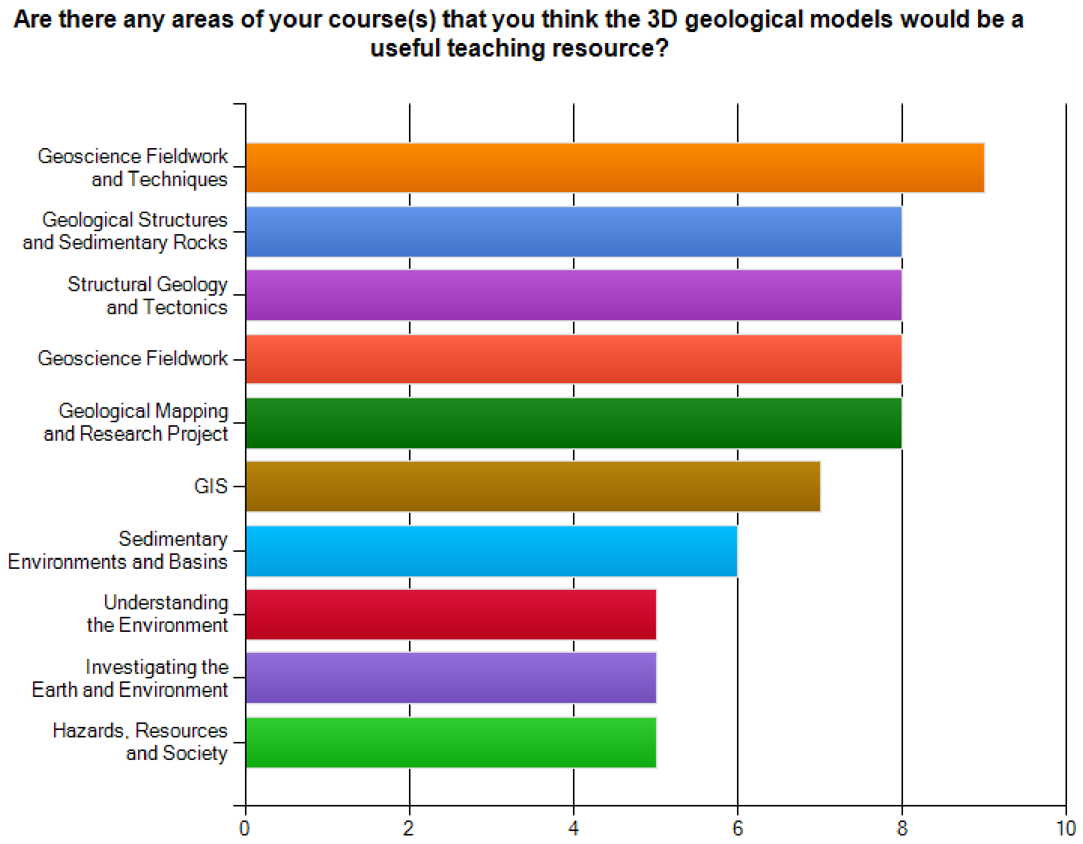

Figure 4: The number of Universities responding to the question: are there any areas of your course(s) that you think the 3D geological models would be a useful teaching resource?

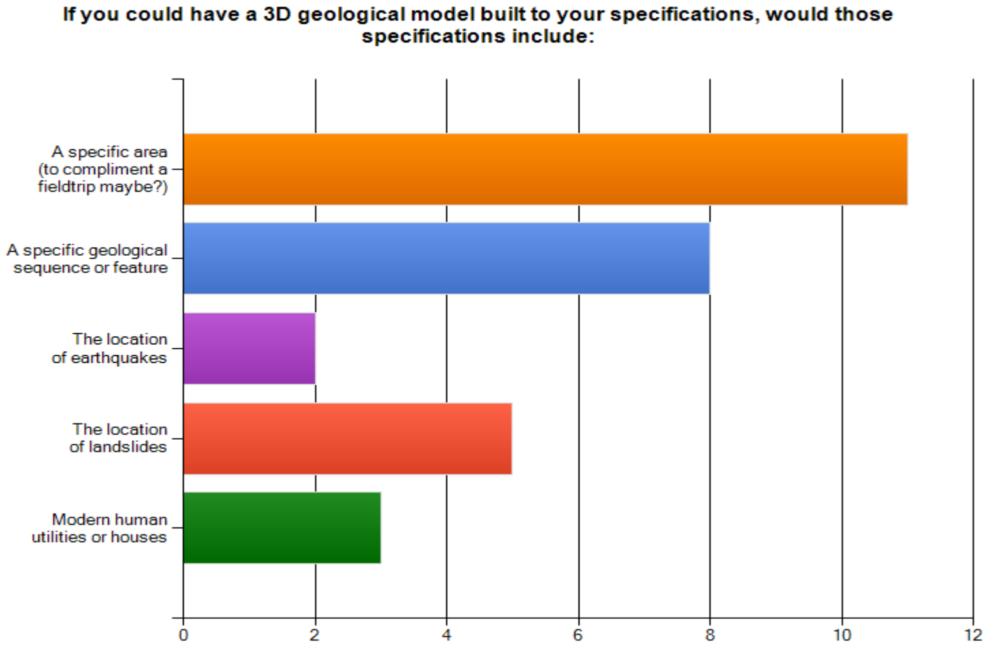

Figure 5: The number of Universities responding to the question: If you could have a 3D geological model built to your specifications, would those specifications include:

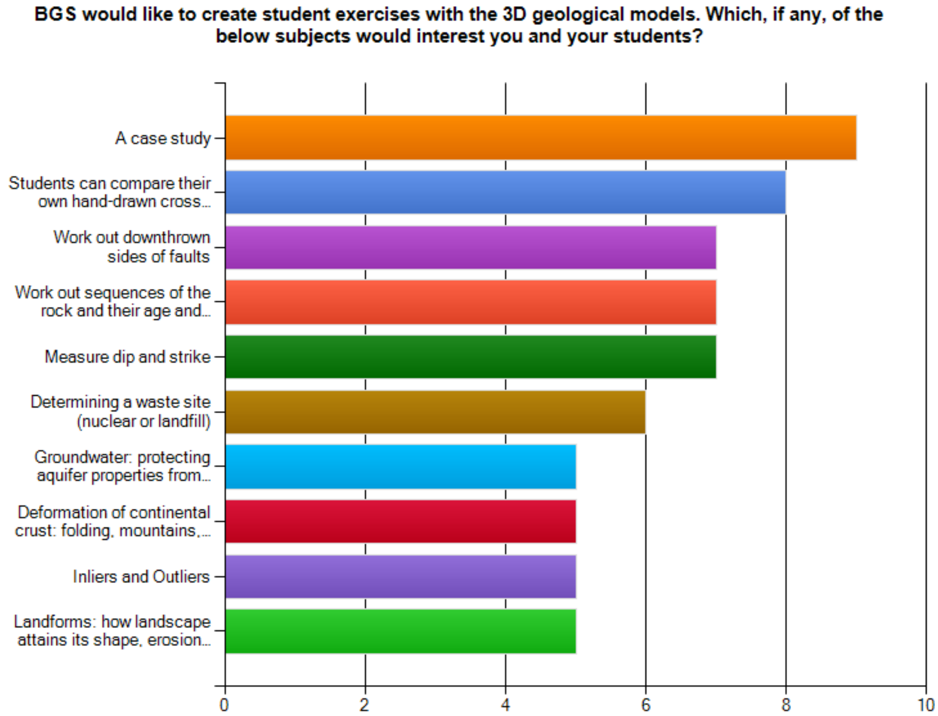

Figure 6: The number of Universities responding to the question: Which of the subjects would interest you for the student exercises?

User Guide.

The questionnaire highlighted that most universities wanted a separate student and tutor user guide. We are therefore working on making an on-screen, quick user guide aimed at new users of the software; a bit like a video tutorial (Figure 7).

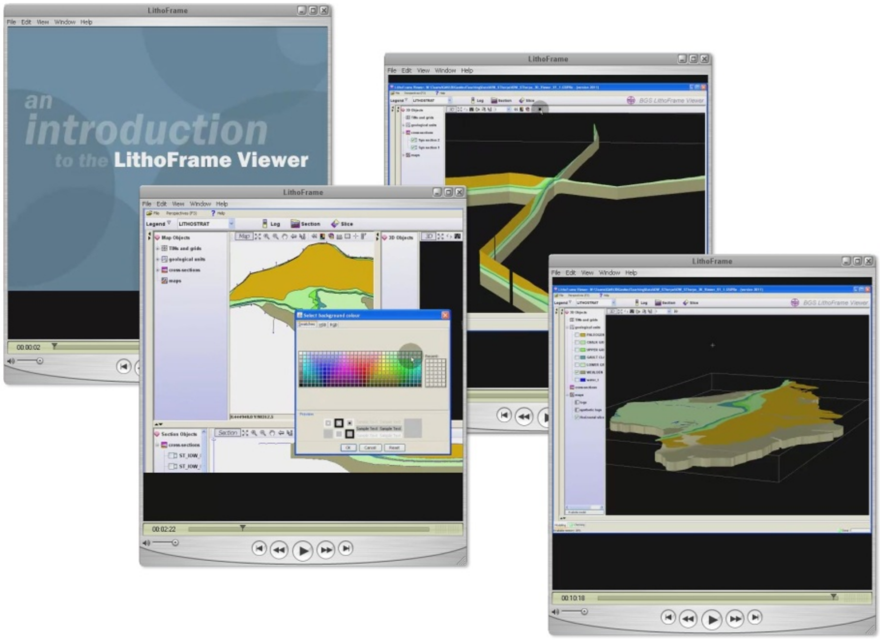

Figure 7: The digital user guide for the 3D model viewer

BGS 3D Educational Geological Models.
BGS are now building 3D geological models for teaching purposes incorporating education strategies that will develop geospatial skills and alleviate potential problems that some students experience. They will be contained within a contemporary case study and show standard geological concepts, structures, sedimentary rocks, cross sections and field techniques. Here are a few models that we have been building this year:

Isle of Wight
The Isle of Wight geological model is going to be used within a groundwater case study with questions on porosity and permeability, the student will be asked to locate the water table and explore aquifer properties (Figure 8).

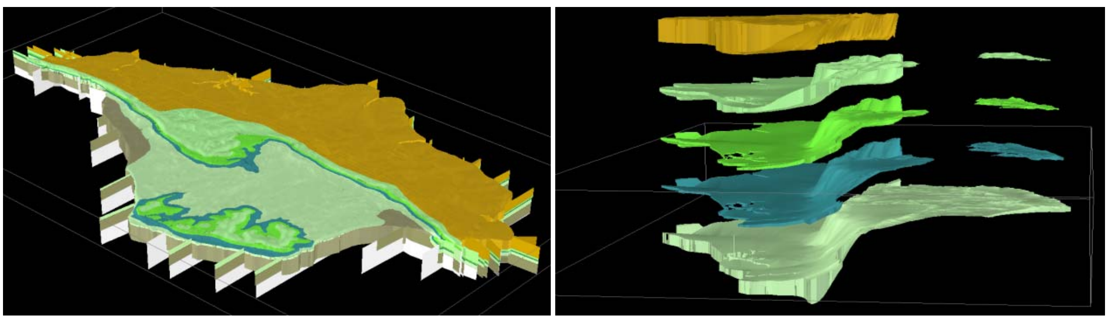

Figure 8: The 3D Geological model of the Isle of Wight

Ingleborough

The model of the Ingleborough area has huge potential for demonstrating where mineral resources come from, exploring where quarries could be sited and the potential socio-economic issues that may present (Figure 9).

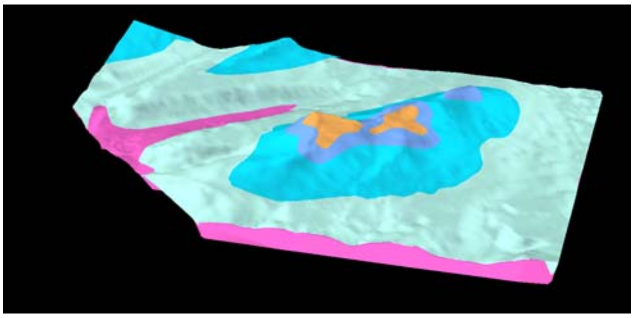

Figure 9: The 3D Geological model of the Ingleborough area

Future Work

Models currently being built are of North-Western Anglesey, Holy Island, Cheddar and Charnwood. We are also compiling some educational material for A Level students using a 3Dpdf of the Isle of Wight model.

Testing the Models

We would like to test the models educational effectiveness and are looking for some new geology undergraduates. If you feel you can help us with this pilot then please get in touch eward@bgs.ac.uk.

Conclusion

3D geological models provide a useful aid to enable a student to observe, manipulate and interpret geology; in particular the models instantly convert two-dimensional geology (maps, boreholes and cross-sections) into three dimensions which is a notoriously difficult geospatial skill to acquire (Kastens & Ishikawa, 2006).

Models can be used either to teach geoscience to complete beginners or add to experienced students body of knowledge. Models could therefore be packaged as a complete educational journey or students and tutors can select certain areas of the model or educational material to incorporate it into an existing area of the syllabus such as a field trip, project work or a certain taxing geological concept such as dip and strike.

3D models as an educational package can be easily utilised by students unable to attend university conventionally (illness or disability), distance learning students or for extra curricular activities and continuing professional development courses. This shouldn't be a problem with data such as DTM's (digital terrain models) as these are only about 20Mb in size. Data can also be saved on ftp servers that students can easily access, no data is streamlined.

3D educational geological models can be used repeatedly and in such a way as to continually build on geoscience aspects – this practice will improve the student's geospatial skills (Hanawalt, 1942 in Kastens & Ishikawa, 2006).

3D geological models can be compared with that seen directly in the field which aids the student in recognising particular patterns or sequences. It also demonstrates how different and complex geology looks in the field and thus how important it is not to rely on models alone!

Student use of 3D geological models is active and the accompanying educational material needs to be engaging, dealing with authentic, contemporary scientific problems meaning the student will have to ask questions, think critically and solve problems (Herbert, 2006 and Rapp- & Uttal, 2006).

3D models can often be more practical and better financial alternatives to some teaching methods currently employed, such as a field trip (Rapp *et al*, 2006).

Learning issues faced by students may also be encountered by experts, policy managers, and stakeholders when dealing with environmental problems. Environmental decision making could be improved by the use of 3D geological models (Herbert, 2006).

3D geological models used in education should incorporate strategies where students first explore and are then introduced to terminology and concepts. Finally students apply their knowledge to different, but related problems. This can be further reinforced and explored with fellow students (Reynolds *et al*, 2006).

3D geological models are a visual tool that encourages greater understanding of geoscience than text can alone (Wilson *et al*, 1998).

The GSI3D model building software is now available for general release through a not-for-profit research consortium. For more information please see the GSI3D website www.GSI3D.org.uk **.**

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